

PATENT ABSTRACTS OF JAPAN

Machine
Translation
Attached.

(11) Publication number : 2002-202238

(43) Date of publication of application : 19.07.2002

(51) Int.Cl.

G01N 13/12
G01N 13/10

(21) Application number : 2000-401627

(71) Applicant : TOSHIBA CORP

(22) Date of filing : 28.12.2000

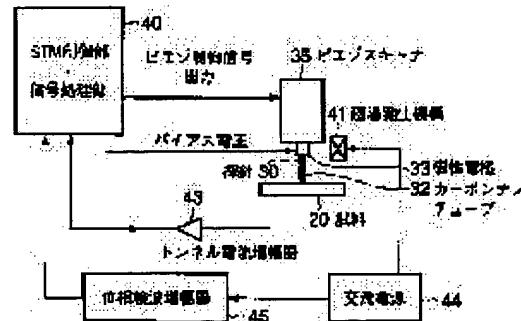
(72) Inventor : OKUNO SHIHO
TANAKA KUNIYOSHI
KISHI TATSUYA

(54) SPIN POLARIZED SCANNING TUNNELING MICROSCOPE, AND REGENERATOR

(57) Abstract:

PROBLEM TO BE SOLVED: To conduct spin detection without generating magnetic interaction between a sample and a probe, and to prevent the probe from being damaged even in the sample having a surface of sharp unevenness.

SOLUTION: This scanning tunneling microscope for observing a magnetic spin of the sample surface at a spatial resolution of several nm or less is provided with the probe 30 comprising a carbon nano-tube 32 coated with a magnetic electrode 33 in several hundred nm of distance from a tip part, a magnetic field generating mechanism 41 for impressing an alternating magnetic field to the magnetic electrode 33 to modulate a magnetizing direction of the electrode 33, an STM control part 40 for impressing a bias voltage between the probe 30 and the sample 20 to conduct control to keep a tunneling current constant, and a phase detection amplifier 45 for extracting a modulation response signal component of the tunneling current accompanied to the magnetic field modulation to detect a magnetic spin condition on the sample surface.



LEGAL STATUS

[Date of request for examination] 28.12.2000

[Date of sending the examiner's decision of] 07.01.2003

rejection]

[Kind of final disposal of application other than
the examiner's decision of rejection or
application converted registration]

[Date of final disposal for application]

[Patent number]

[Date of registration]

[Number of appeal against examiner's
decision of rejection]

[Date of requesting appeal against examiner's
decision of rejection]

[Date of extinction of right]

Copyright (C); 1998,2003 Japan Patent Office

* NOTICES *

Japan Patent Office is not responsible for any damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. **** shows the word which can not be translated.
3. In the drawings, any words are not translated.

PRIOR ART

[Description of the Prior Art] The magnetic-force microscope is known as a magnetic-domain observation means for evaluating the detailed magnetic-domain structure on the front face of the magnetic substance by which resolution is the highest. The resolution of this magnetic-force microscope is a maximum of about 10nm. On the other hand, further resolution enhancement of detailed magnetic-domain observation technology is overly desired overly with [medium / magnetic-recording] detailed-izing.

[0003] a scanning tunneling microscope (Scanning Tunneling Microscopy) scans a probe relatively to a sample on a sample front face by making a sample or a probe drive, and a tunnel current is very sensitive to the distance between probe-samples -- using -- the structure on the front face of a sample, and physical properties -- an atom -- it is the technique evaluated by resolution since spin polarization of the tunnel electron is carried out in this scanning tunneling microscope when the magnetic substance is used as a sample or a probe, if a spin state can be classified -- atomic level -- the magnetic information on the front face of a sample can be acquired with resolution

[0004] The method of acquiring spin information from the tunnel-current change depending on the spin between magnetic-substance sample front faces is indicated by reference (R. Wissendanger, H.J.Guntherodt, G.Guntherodt, R.J.Gambino and R.Ruf, Physical Review Letters, vol.65, p247 (1990)), using a ferromagnetic probe as such a spin polarization scanning tunneling microscope. In these examples of observation using the ferromagnetic probe, the sense of magnetization is displayed as contrast.

[0005] However, spin information superimposed the image obtained by these well-known examples on the surface concavo-convex image, and it had the fault that a surface form and spin arrangement could not take out only a spin image from a strange actual sample front face. The method of using the difference in the degree of spin polarization to bias voltage as a method of solving this is JP,2000-131215,A and reference (M. Bode, M.Getzlaff, and R.Wiesendangerer, Physical Review Letters, vol.81, p4256 (1998)). O. It is indicated by Pietzsch, A.Kubetzka, M.Bode, and R.Wiesendangerer, Physical Review Letters, vol.84, and p5212 (2000).

[0006] However, even if it was in this kind of equipment, it was difficult to avoid the following problems. That is, since a probe is ferromagnetism, the mutual magnetic influence of a sample and a probe may occur, and the accuracy of measurement may deteriorate. Moreover, when the irregularity on the front face of a sample was intense, it could not avoid that a probe contacted a sample front face, but there was a fault of being easy to damage a probe.

[Translation done.]

* NOTICES *

Japan Patent Office is not responsible for any damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. **** shows the word which can not be translated.
3. In the drawings, any words are not translated.

TECHNICAL FIELD

[The technical field to which invention belongs] Especially this invention relates to the spin polarization scanning tunneling microscope suitable for observing the magnetic structure of a magnetic material, or the magnetic-domain structure of a ferromagnetic by the spatial resolving power several nm or less, and the regenerative apparatus using this with respect to a scanning tunneling microscope.

[Translation done.]

* NOTICES *

Japan Patent Office is not responsible for any damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. **** shows the word which can not be translated.
3. In the drawings, any words are not translated.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] Especially this invention relates to the spin polarization scanning tunneling microscope suitable for observing the magnetic structure of a magnetic material, or the magnetic-domain structure of a ferromagnetic by the spatial resolving power several nm or less, and the regenerative apparatus using this with respect to a scanning tunneling microscope.

[0002]

[Description of the Prior Art] The magnetic-force microscope is known as a magnetic-domain observation means for evaluating the detailed magnetic-domain structure on the front face of the magnetic substance by which resolution is the highest. The resolution of this magnetic-force microscope is a maximum of about 10nm. On the other hand, further resolution enhancement of detailed magnetic-domain observation technology is overly desired overly with [medium / magnetic-recording] detailedizing.

[0003] a scanning tunneling microscope (Scanning Tunneling Microscopy) scans a probe relatively to a sample on a sample front face by making a sample or a probe drive, and a tunnel current is very sensitive to the distance between probe-samples -- using -- the structure on the front face of a sample, and physical properties -- an atom -- it is the technique evaluated by resolution since spin polarization of the tunnel electron is carried out in this scanning tunneling microscope when the magnetic substance is used as a sample or a probe, if a spin state can be classified -- atomic level -- the magnetic information on the front face of a sample can be acquired with resolution

[0004] The method of acquiring spin information from the tunnel-current change depending on the spin between magnetic-substance sample front faces is indicated by reference (R. Wissendanger, H.J.Guntherodt, G.Guntherodt, R.J.Gambino and R.Ruf, Physical Review Letters, vol.65, p247 (1990)), using a ferromagnetic probe as such a spin polarization scanning tunneling microscope. In these examples of observation using the ferromagnetic probe, the sense of magnetization is displayed as contrast.

[0005] However, spin information superimposed the image obtained by these well-known examples on the surface concavo-convex image, and it had the fault that a surface gestalt and spin arrangement could not take out only a spin image from a strange actual sample front face. As a method of solving this The difference in the degree of spin polarization to bias voltage the method of using -- JP,2000-131215,A and reference (M. -- Bode, M.Getzlaff, and R.Wiesendangerer, Physical Review Letters, vol.81, and p4256 (1998) --) It is indicated by O.Pietzsch, A.Kubetzka, M.Bode, and R.Wiesendangerer, Physical Review Letters, vol.84, and p5212 (2000).

[0006] However, even if it was in this kind of equipment, it was difficult to avoid the following problems. That is, since a probe is ferromagnetism, the mutual magnetic influence of a sample and a probe may occur, and the accuracy of measurement may deteriorate. Moreover, when the irregularity on the front face of a sample was intense, it could not avoid that a probe contacted a sample front face, but there was a fault of being easy to damage a probe.

[0007]

[Problem(s) to be Solved by the Invention] Thus, in the conventional spin polarization scanning tunneling microscope, since the probe of what can acquire the spin information on a magnetic-substance

sample front face by using the probe of a ferromagnetic was ferromagnetism, the mutual magnetic influence of a sample and a probe might occur, and there was a fault of being easy to damage a probe. [0008] this invention is to offer the spin polarization scanning tunneling microscope which it was able to accomplish in consideration of the above-mentioned situation, and the place made into the purpose can perform spin detection without the magnetic interaction of a sample and a probe, and can prevent breakage of a probe also to a sample with intense surface irregularity.

[0009]

[Means for Solving the Problem] (Composition) In order to solve the above-mentioned technical problem, this invention has adopted the following composition.

[0010] Namely, this invention is set to the spin polarization scanning tunneling microscope for observing the magnetic spin state on the front face of a sample by the spatial resolving power several nm or less. The probe which consists of a carbon nanotube which put the magnetic electrode on the field within predetermined distance from the point, The magnetic field developmental mechanics to which an alternating current magnetic field is impressed to the aforementioned magnetic electrode, and the magnetization direction of this magnetic electrode is changed periodically, The source of bias voltage which impresses predetermined voltage between the scanner which makes the aforementioned probe scan relatively to a sample front face, and the aforementioned probe and a sample, The current detection mechanism in which the tunnel current which flows between the aforementioned probe and a sample is detected, The drive which drives the aforementioned probe in the height direction so that the average of the aforementioned tunnel current may become fixed, and the magnetic spin detection mechanism in which extract the alternating current reply signal component of the tunnel current accompanying change of the aforementioned magnetization direction, and the magnetic spin state on the front face of a sample is detected are provided, and it is characterized by the bird clapper.

[0011] Here, the following are mentioned as a desirable embodiment of this invention.

(1) A magnetic electrode material should be Fe, Co, nickel, Cr, Mn, an alloy containing these at least one, or a compound.

(2) The magnetic electrode should be arranged from the nose of cam of a carbon nanotube at the distance within spin diffusion length (generally several 100nm).

(3) Keep the distance of a sample and a probe at 10nm from 0.1nm.

(4) Magnetic field developmental mechanics should consist of a coil, and alternating current should be supplied to it. Furthermore, the frequency of alternating current should be 100Hz - 100kHz.

(5) A means to image the alternating current reply signal component of the detected tunnel current was established.

[0012] Moreover, the magnetic-recording medium with which magnetic recording is presented in the regenerative apparatus for this invention reproducing magnetic information, The probe which consists of a carbon nanotube which put the magnetic electrode on the field within predetermined distance from the point, The magnetic field developmental mechanics to which an alternating current magnetic field is impressed to the aforementioned magnetic electrode, and the magnetization direction of this magnetic electrode is changed periodically, The scanner which makes the aforementioned probe scan relatively to a magnetic-recording medium front face, The source of bias voltage which impresses predetermined voltage between the aforementioned probe and a magnetic-recording medium, The current detection mechanism in which the tunnel current which flows between the aforementioned probe and a magnetic-recording medium is detected, The drive which drives the aforementioned probe in the height direction so that the aforementioned tunnel current may become fixed, and the magnetic spin detection mechanism in which extract the alternating current reply signal component of the tunnel current accompanying change of the aforementioned magnetization direction, and the magnetic spin state of a magnetic-recording medium front face is detected are provided, and it is characterized by the bird clapper.

[0013] (Operation) this invention constitutes the probe from the carbon nanotube which put the magnetic electrode on the field within predetermined distance from the point. It is reported that spin diffusion length exceeds several 100nm, and a carbon nanotube has the feature that an electron flows maintaining a spin state when the electron which had spin from the end side was passed. Therefore, if the magnetic electrode is prepared in the distance within spin diffusion length from the nose of cam of a

carbon nanotube and this magnetic electrode is made to magnetize in a certain direction, magnetic reluctance will change according to the relation between the magnetization direction of a magnetic electrode, and the direction of an electron spin, and a tunnel current will also change. That is, even if it uses the probe which consists of a carbon nanotube and a magnetic electrode as mentioned above, it becomes possible to measure the magnetic spin state on the front face of a sample like the case where a probe nose of cam is formed with a ferromagnetic.

[0014] And in this case, since the probe itself is nonmagnetic (the nose of cam of a probe is a carbon nanotube, and non-magnetic material), it can avoid the influence of the probe magnetization by sample magnetization, or its reverse. Furthermore, even if the nose of cam of a carbon nanotube contacts a sample front face, it will be satisfactory, and it becomes possible from a carbon nanotube having a high elastic modulus to prevent breakage of a probe.

[0015]

[Embodiments of the Invention] Before explaining an operation gestalt, the basic principle of this invention is explained.

[0016] A carbon nanotube has the tube-like structure where the graphite sheet was rounded off spirally. Although a tube has the thing of a monolayer, and a multilayer thing, each can be used as a probe of this invention. The nose of cam (A) which is an end of this carbon nanotube separates the interval of 0.1 to 10nm on a sample front face, and is arranged on it. Height adjustment of the height is serially carried out during a scan so that the average of the tunnel current which flows between a carbon nanotube and a sample may turn into a fixed value. A magnetic electrode is prepared in the end face (B) side which is the other end of a carbon nanotube. As long as this magnetic electrode is installed in 800nm or less below spin diffusion length (several 100nm) from the nose of cam (A) of a carbon nanotube, it may not be a perfect edge. The distance from a nose of cam (A) is 500nm or less still more preferably.

[0017] A magnetic electrode is an electrode for catching the tunnel current from the sample front face which has flowed the carbon nanotube. the soft-magnetism alloy of the alloy which contains Fe, Co, nickel, Mn, Cr, and these as an electrode material which can be adapted for this invention, the NiFe system alloy called permalloy, a CoNbZr system, a FeTaC system, a CoTaZr system, a FeAlSi system, a FeB system, and a CoFeB system, a Heusler alloy, CrO₂ and Fe 3O₄, and La_{1-x} Sr_x MnO₃ etc. -- the half metal magnetic substance is mentioned

[0018] It is desirable and the soft magnetic materials of a permalloy or an amorphous system are Co, Fe, CoFe, and Fe 3O₄, when controlling a magnetic electrode. It is desirable although a big spin signal is acquired. Moreover, Co and CoFe to which a magnetic electrode has the thickness of 3nm or less in the portion which contacts directly [of carbon nano CHUBUHE], or Fe 3O₄ If it is made to form and soft magnetic materials, such as a permalloy, are made to form on it, it excels in the controllability of a magnetic electrode, and a big spin signal can be acquired.

[0019] The magnetic field developmental mechanics which controls the magnetization direction is attached in the latest of this magnetic electrode. Magnetic field developmental mechanics consists of the lead wire of the shape of the shape of a coil, and a non-coil. Furthermore, the alternating current power supply 10Hz or more for carrying out an electric power supply is connected to the magnetic field developmental mechanics. An alternating current magnetic field occurs by the current from this alternating current power supply, and the magnetization direction of a magnetic electrode is modulated. And the spin component of a tunnel current is detectable by establishing the modulation reply signal component detection mechanism of the electrode current accompanying this magnetic field modulation.

[0020] The perpendicular magnetization component of a sample is detectable by rolling a coil or preparing lead wire at right angles to a probe shaft centering on a probe shaft, so that the direction of a generating magnetic field from magnetic field developmental mechanics may become parallel to a probe shaft. Moreover, the magnetization component within a field of a sample parallel to the magnetic field impression direction is detectable by installing a coil beside an electrode or preparing lead wire in it in parallel with a probe shaft so that a magnetic field may become right-angled on a probe shaft. magnetic field developmental mechanics -- one magnetic electrode -- receiving -- one set -- or you may put two or more sets in order By changing mutually, the frequency of the alternating current impressed here can determine the magnetization vector of a sample as two or more sets of the cases.

[0021] Finally, although drive-system blunder UNTO of the piezo scanner etc. is carried out, as for the

probe (carbon nanotube with a magnetic electrode) of this invention, inclusion may exist between a magnetic electrode and a drive system. The example is shown in drawing 1. In drawing 1 (a), after attaching a carbon nanotube 12 to the point of the usual probe 11 with Van der Waals force first, the magnetic electrode 13 was deposited to jointing. And the usual probe 11 was attached in the drive systems 15, such as a piezo-electric element. At drawing 1 (b), after placing a carbon nanotube 12 so that a nose of cam may jump out on the board 14 of an insulator, while forming the magnetic electrode 13 by carrying out the vacuum evaporationo of the magnetic substance, adhesion was also performed now. (a) and (b) form wiring in the magnetic electrode 13, and it is made for current to have flowed. [0022] Drawing 2 is the example which formed the coil 18 as magnetic field developmental mechanics, this coil 18 is rolled centering on the probe shaft, and a magnetic field impresses it to the shaft orientations of a probe. And the magnetization direction of the magnetic electrode 13 is modulated by considering the current passed in a coil 18 as an alternating current.

[0023] In addition, indispensable basic structures other than the above as a scanning tunneling microscope are the current detection mechanisms in which the tunnel current which flows between the drive which makes a probe scan relatively to a sample front face, the source of bias voltage and probe which impress bias voltage between a probe and a sample, and a sample is detected. The spin polarization scanning tunneling microscope of this invention can make basic structure the same, and can use it for a regenerative apparatus as it is. Such a regenerative apparatus especially fits reproduction of a high-density record medium.

[0024] Hereafter, the operation gestalt of illustration of the detail of this invention explains.

[0025] (1st operation gestalt) Drawing 3 is drawing showing the basic composition of the spin polarization scanning tunneling microscope concerning the 1st operation gestalt of this invention.

[0026] The probe 30 has structure shown for example, in aforementioned drawing 1 (a), and consists of a carbon nanotube 32 and magnetic electrode 33 grade. A end face side is fixed to the piezo scanner 35, and, as for this probe 30, the relative scan of the nose of cam (carbon nanotube side) is carried out to the front face of a sample 20. Near the probe 30, the magnetic field developmental mechanics 41 for impressing a magnetic field to the magnetic electrode 33 is arranged. This magnetic field developmental mechanics 41 is the coil rolled centering on the probe shaft, as shown for example, in aforementioned drawing 2, and it is driven by AC power supply 44.

[0027] Bias voltage is impressed to the magnetic electrode 33 of a probe 30 by STM control / signal-processing section 40. The tunnel current which flows between a probe 30 and a sample 20 by impression of this bias voltage is amplified by the tunnel-current amplifier 43, and is inputted into STM control / signal-processing section 40, and the phase-detection amplifier 45 mentioned later. And in STM control / signal-processing section 40, the piezo control signal for driving the piezo scanner 35 is outputted so that the average of a tunnel current may become fixed.

[0028] Moreover, the alternating current signal by AC power supply 44 is supplied to the phase-detection amplifier 45 as a modulating signal. In the phase-detection amplifier 45, the synchronous detection of the tunnel current obtained through amplifier 43 is carried out based on the modulating signal from AC power supply 44. Here, the component depending on magnetic spin is in a tunnel current, and since this changes a lot by carrying out the alternating current drive of the magnetic field developmental mechanics 41, if a signal is taken out according to an alternating current drive, it can take out a spin component. That is, it becomes possible by detecting a tunnel current as mentioned above synchronizing with an alternating current signal to detect only the magnetization component on the front face of a sample.

[0029] In addition, although the piezo scanner 35 was used for the scan on the sample front face of a probe 30, and vertical movement of a probe 30, the piezo scanner 35 is used only for vertical movement of a probe 30, and you may make it move the stage in which the sample 20 was laid in the above-mentioned explanation, in order to scan a probe 30 on a sample front face.

[0030] In the above-mentioned composition, the laminating electrode of CoFe/permalloy was prepared as a carbon nanotube 32 HE magnetism electrode 33, it mounted on the piezo scanner 35, and the spin polarization scanning tunneling microscope was tested. as a laminating electrode -- Co/permalloy, Fe/permalloy, etc. -- desirable -- instead of [of this permalloy] -- soft-magnetism amorphous ** -- it is desirable CoFe, and Co and Fe touch a carbon nanotube. The thickness of soft magnetic materials, such

as 0.3-2nm and a permalloy, has [the thickness of CoFe, and Co and Fe] desirable 1-30nm. As magnetic field developmental mechanics 41 for making the magnetic electrode 33 magnetize, as shown in drawing 2, the coil was rolled by having made the magnetic electrode into the medial axis, AC power supply 44 performed magnetic field generating of 10G on the frequency of 777Hz, and the phase-detection amplifier 45 detected the component which synchronized with the magnetic field modulation among tunnel currents.

[0031] The probe 30 was scanned on the sample 20, controlling the height of a probe 30 so that a tunnel current is set to 0.2nA(s) using Co perpendicular magnetic anisotropy films as a sample 20. That to which the topology on the front face of a sample made the output of the phase-detection amplifier 45 the picture signal from the screen which made the height position of a probe 30 the picture signal indicated unrelated contrast to be a TOPOGURAFU image, and this contrast disappeared by the pulse magnetic field impression of 3kG(s) to a sample 20. Moreover, the signal from a nonmagnetic substrate portion was zero. From the above result, it checked that the output signal of the phase-detection amplifier 45 had detected the magnetization state on the front face of a sample.

[0032] Moreover, it asked for spin signal strength with the phase-detection amplifier 45 from the Co sample 20 using the probe 30 which prepared the CoFe electrode as a magnetic electrode 33 in the place of 300nm of distance from the nose of cam (A) of a carbon nanotube 32 with the composition of the same spin polarization scanning tunneling microscope as drawing 3. As an example of comparison, this of the tungsten probe which is nonmagnetic also asked for spin signal strength with the phase-detection amplifier 45 from Co sample using what prepared the CoFe electrode in the place of 300nm of distance from the nose of cam.

[0033] The latter is undetectable on below noise level to the former of the resistance rate of change which standardized the size of a modulation reply signal with the tunnel-current value having been 5%. With this operation gestalt, a carbon nanotube 32 has long spin diffusion length, and resistance rate of change changes for holding the spin state on the front face of a sample as it is, reaching the magnetic electrode 33, and the magnetoresistance effect happening here. Moreover, when the electrode position was established in the place of 150nm of distance from the nose of cam (A) of a carbon nanotube 32 and comparative experiments were conducted, resistance rate of change increased to 15% or more. From this result, the installation position of the magnetic electrode 33 understands a thing with the nearer desirable one at the nose of cam (A) of a carbon nanotube 32.

[0034] Moreover, the sample front face which has the surface irregularity of 10nm for the probe 30 which consists of a carbon nanotube 32, and the usual tungsten probe was made to scan using the same spin polarization scanning tunneling microscope as drawing 3, and the resistance test of a probe was performed. Consequently, in a tungsten probe, the image by the carbon nanotube did not change to the image having become double with 3 times of scans. In this result, the shock resistance of a carbon nanotube shows high **.

[0035] Thus, according to this operation gestalt, the magnetic spin state on the front face of a sample can be measured like the case where a probe nose of cam is formed with a ferromagnetic, by detecting a tunnel current, constituting a probe 30 from a carbon nanotube 32 which put the magnetic electrode 33 on the distance within spin diffusion length from the point, and modulating the magnetization direction of the magnetic electrode 33 according to the magnetic field impression mechanism 41.

[0036] Moreover, with this operation gestalt, since the nose of cam of a probe 30 is a carbon nanotube 32 and is non-magnetic material, it can avoid the influence of the probe magnetization by sample magnetization, or its reverse. Furthermore, a carbon nanotube 32 will be satisfactory even if the nose of cam of a carbon nanotube 32 contacts a sample front face, and it becomes possible [preventing breakage of a probe 30] from having a high elastic modulus. That is, spin detection can be performed without the magnetic interaction of a sample and a probe, and breakage of a probe can be prevented also to a sample with intense surface irregularity.

[0037] (2nd operation gestalt) Drawing 4 is the cross section showing the important section composition of the regenerative apparatus concerning the 2nd operation gestalt of this invention.

[0038] 60 in drawing is a probe and this probe 60 consists of a carbon nanotube 62 and magnetic electrode 63 grade like the previous operation gestalt. The large field mechanical component for the minute mechanical component which carries out the minute drive of the probe 60 in order that 65 may

make a tunnel current regularity, and 67 driving two or more probes 60 simultaneously, and 69 show magnetic field developmental mechanics, and 70 shows the magnetic-recording medium.

[0039] With this operation gestalt, what mounted the carbon nanotube 62 which has the magnetic electrode 63 on the minute mechanical component 65, and was made into one unit was arranged in multi-unit 1 train, and corresponded and carried out large field mechanical-component 67 blunder UNTO to a still bigger distance. This constituted the magnetic-head section. The source of bias voltage (not shown) and the magnetic field developmental mechanics 69 to a multi-unit of the magnetic-head section were set to one, respectively. And a minute gap shall be separated on the front face of the magnetic-recording medium 70, two or more carbon nanotubes 62 shall be arranged on it, and the scan of these shall be carried out relatively.

[0040] More specifically, the piezo-electric element as the magnetic electrode 63, the magnetic field developmental mechanics 69, and a minute mechanical component 65 etc. was produced by micro processing. 50 probes 60 were put in order and taken as the probe array. The magnetic field developmental mechanics 69 becomes the flank of the magnetic electrode 63 from the thin line by which contiguity arrangement was carried out, and requires the magnetic field it turned [magnetic field] to the shaft orientations of a carbon nanotube 62 to the magnetic electrode 63 by the current passed here. It set to up to the magnetic-recording medium 70 by making into one unit the carbon nanotube array and the magnetic field developmental mechanics 69 containing the magnetic electrode 63 which formed wiring.

[0041] Since it was pillar-shaped, the medium which made the becoming pattern with a diameter of 7nm each record bit was used for the magnetic-recording medium 70. The whole magnetic-head section is relatively moved to this magnetic-recording medium 70. In drawing 4, the magnetic-head section is moved in a space longitudinal direction and the direction of the space table reverse side. The travel d of a space longitudinal direction has $d=r$ and a desirable bird clapper at the maximum, when distance between carbon nanotubes is set to r. If the number of a carbon nanotube is set to n, reading of the medium field which has the width of face of xd on the whole $(n+1)$ will become possible.

[0042] The record bit information on travel within the limits is read by each probe, moving the magnetic-head section. Specifically, phase-detection amplifier detects a magnetic field modulation reply signal component among the signals from each magnetic electrode, and it considers as each output signal. In addition, although it consists of an array of one train drawing, high-speed processing is also still more possible by making it a matrix array like 50x50. In addition, although it is necessary to make space move the distance corresponding to medium length about a vertical drive in arrangement of drawing 4 in the case of 1 train array, in the case of a matrix array, it ends with the travel to the next probe.

[0043] As a result of examining the regenerative signal in the above method, it checked that the record state of the magnetic-recording medium corresponding to the recording density of 1Tbpsi could be read.

[0044] Thus, according to this operation gestalt, the magnetic information recorded on the magnetic-recording medium can be read by using the probe which consists of a carbon nanotube, a magnetic electrode, etc. as the magnetic head. And since the resolution of the magnetic spin by the probe is very high, read-out of the magnetic-recording medium corresponding to the recording density of 1Tbpsi also becomes possible. Moreover, high-speed processing of read-out can also be aimed at by arranging a probe a seriate or in the shape of a matrix. Moreover, like the 1st operation gestalt, since the carbon nanotube is used for the point of a probe, the magnetic interaction of a probe and a magnetic-recording medium can be abolished, and the reinforcement of a probe can also be achieved.

[0045] In addition, this invention is not limited to each operation gestalt mentioned above. The direction which makes a magnetic electrode magnetize may not necessarily be restricted to probe shaft orientations, and may be a direction level on a probe shaft. What is necessary is to arrange a coil to the flank of a magnetic electrode, or just to prepare a thin line in the upper part of a magnetic electrode, when you make it magnetized horizontally. Furthermore, magnetic field developmental mechanics may not necessarily be restricted to one, may be prepared, and may use each synthetic magnetic field. [two or more] The position in which a magnetic electrode is prepared should just usually be less than 800nm that what is necessary is just the distance between the nose of cam of a carbon nanotube, and spin diffusion length. Furthermore, the material of a magnetic electrode can be suitably changed according to specification.

[0046] moreover, in the 2nd operation gestalt, although two or more probes were boiled and were carried out, it comes out by one probe not to mention the thing you may make it read the information on a magnetic-recording medium Furthermore, in the 2nd operation gestalt, it is also possible to form a magnetic-recording medium in disc-like, to arrange a carbon nanotube on the straight line passing through the center of a magnetic-recording medium, to rotate a magnetic-recording medium, and to read magnetic information.

[0047] In addition, in the range which does not deviate from the summary of this invention, it can deform variously and can carry out.

[0048]

[Effect of the Invention] As explained in full detail above, according to this invention, the magnetic structure of a magnetic material or the magnetic-domain structure of a ferromagnetic is observable by the spatial resolving power several nm or less by constituting the probe of a spin polarization scanning tunneling microscope from a magnetic electrode arranged from the nose of cam of a nonmagnetic carbon nanotube and this carbon nanotube to the field within predetermined distance. And since a carbon nanotube is nonmagnetic, the mutual influence of probe magnetization and sample magnetization is avoidable, and since a carbon nanotube has a high elastic modulus, breakage of a probe can be prevented also to a sample with intense surface irregularity.

[Translation done.]

* NOTICES *

Japan Patent Office is not responsible for any damages caused by the use of this translation.

1. This document has been translated by computer. So the translation may not reflect the original precisely.
 2. **** shows the word which can not be translated.
 3. In the drawings, any words are not translated.
-

CLAIMS

[Claim(s)]

[Claim 1] The spin polarization scanning tunneling microscope characterized by providing the following. The probe which consists of a carbon nanotube which put the magnetic electrode on the field within predetermined distance from the point. Magnetic field developmental mechanics to which an alternating current magnetic field is impressed to the aforementioned magnetic electrode, and the magnetization direction of this magnetic electrode is changed periodically. The scanner which makes the aforementioned probe scan relatively to a sample front face. The current detection mechanism in which the tunnel current which flows between the source of bias voltage which impresses predetermined voltage between the aforementioned probe and a sample, and the aforementioned probe and a sample is detected, the drive which drives the aforementioned probe in the height direction so that the average of the aforementioned tunnel current may become fixed, and the magnetic spin detection mechanism in which extract the alternating current reply signal component of the tunnel current accompanying change of the aforementioned magnetization direction, and the magnetic spin state on the front face of a sample is detected.

[Claim 2] The aforementioned magnetic electrode material is Fe, Co, nickel, Cr, Mn, an alloy containing these at least one, or a spin polarization scanning tunneling microscope according to claim 1 characterized by being a compound.

[Claim 3] The regenerative apparatus which possesses a spin polarization scanning tunneling microscope according to claim 1 and the magnetic-recording medium by which a surface magnetic spin state is detected by the probe of the aforementioned microscope, and is characterized by the bird clapper.

[Translation done.]

(19)日本国特許庁 (JP)

(12) 公開特許公報 (A)

(11)特許出願公開番号

特開2002-202238

(P2002-202238A)

(43)公開日 平成14年7月19日 (2002.7.19)

(51)Int.Cl.
G 0 1 N 13/12

識別記号

13/10

F I
G 0 1 N 13/12

13/10

データード(参考)
A
D
G

審査請求 有 請求項の数3 OL (全7頁)

(21)出願番号 特願2000-401627(P2000-401627)

(22)出願日 平成12年12月28日 (2000.12.28)

(出願人による申告) 「国などの委託研究の成果に係る特許出願(平成12年度新エネルギー・産業技術総合開発機構「超先端電子技術開発促進事業(超先端電子技術開発促進事業)」委託研究、産業活力再生特別措置法第30条の適用を受けるもの)」

(71)出願人 000003078

株式会社東芝

東京都港区芝浦一丁目1番1号

(72)発明者 奥野 志保

神奈川県川崎市幸区小向東芝町1番地 株式会社東芝研究開発センター内

(72)発明者 田中 国義

神奈川県川崎市幸区小向東芝町1番地 株式会社東芝研究開発センター内

(72)発明者 岸 達也

神奈川県川崎市幸区小向東芝町1番地 株式会社東芝研究開発センター内

(74)代理人 100058479

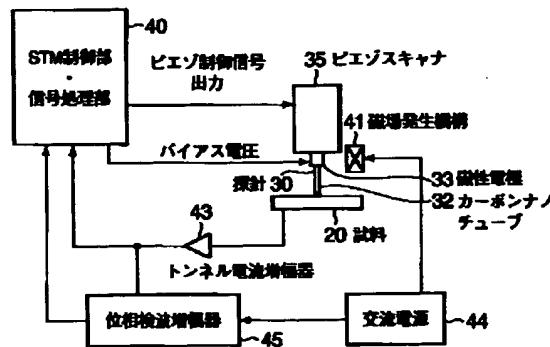
弁理士 鈴江 武彦 (外6名)

(54)【発明の名称】スピン偏極走査型トンネル顕微鏡及び再生装置

(57)【要約】

【課題】 試料と探針との磁気的相互作用なしにスピン検出を行うことができ、且つ表面凹凸が激しい試料に対しても探針の破損を防止できる。

【解決手段】 試料表面の磁気スピンを数nm以下の空間分解能で観察するためのスピン偏極走査型トンネル顕微鏡において、先端部から数100nmの距離に磁性電極33と被着したカーボンナノチューブ32からなる探針30と、磁性電極33に対し交流磁場を印加して磁性電極33の磁化方向を変調する磁場発生機構41と、探針30と試料20との間にバイアス電圧を印加し、トンネル電流が一定となるように制御するSTM制御部40と、磁場変調に伴うトンネル電流の変調応答信号成分を抽出して試料表面の磁気スピン状態を検出する位相検波増幅器45とを備えた。



【特許請求の範囲】

【請求項1】先端部から所定距離以内の領域に磁性電極を被着したカーボンナノチューブからなる探針と、前記磁性電極に対し交流磁場を印加して該磁性電極の磁化方向を周期的に変化させる磁場発生機構と、前記探針を試料表面に対して相対的に走査させる走査機構と、前記探針と試料との間に所定の電圧を印加するバイアス電圧源と、前記探針と試料との間に流れるトンネル電流を検出する電流検出機構と、前記トンネル電流の平均値が一定となるように前記探針を高さ方向に駆動する駆動機構と、前記磁化方向の変化に伴うトンネル電流の交流応答信号成分を抽出して試料表面の磁気スピニ状態を検出する磁気スピニ検出機構とを具備してなることを特徴とするスピニ偏極走査型トンネル顕微鏡。

【請求項2】前記磁性電極材料は、Fe, Co, Ni, Cr, Mn, 若しくはこれらの少なくとも一つを含む合金、又は化合物であることを特徴とする請求項1記載のスピニ偏極走査型トンネル顕微鏡。

【請求項3】請求項1記載のスピニ偏極走査型トンネル顕微鏡と、前記顕微鏡の探針で表面の磁気スピニ状態が検出される磁気記録媒体とを具備してなることを特徴とする再生装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、走査型トンネル顕微鏡に係わり、特に磁性材料の磁気構造或いは強磁性体の磁区構造を数nm以下の空間分解能で観察するのに適したスピニ偏極走査型トンネル顕微鏡、及びこれを用いた再生装置に関する。

【0002】

【従来の技術】磁性体表面の微細磁区構造を評価するための最も分解能の高い磁区観察手段として、磁気力顕微鏡が知られている。この磁気力顕微鏡の分解能は最高で10nm程度である。これに対して、磁気記録媒体等の超微細化に伴い、超微細磁区観察技術の更なる分解能向上が望まれている。

【0003】走査型トンネル顕微鏡(Scanning Tunneling Microscopy)は、試料或いは探針を駆動させることにより探針を試料表面上で試料に対し相対的に走査し、トンネル電流が探針-試料間距離に対して極めて敏感であることをを利用して、試料表面の構造、物性を原子分解能で評価する手法である。この走査型トンネル顕微鏡において、試料或いは探針として磁性体を用いた場合には、トンネル電子はスピニ偏極するため、スピニ状態を分別できれば原子レベル分解能で試料表面の磁気情報を得ることができる。

【0004】このようなスピニ偏極走査型トンネル顕微鏡として、強磁性体探針を用い、磁性体試料表面との間のスピニに依存したトンネル電流変化からスピニ情報を得る方法が文献(R.Wissendanger, H. J. Guntherodt, G.

Guntherodt, R.J.Gambino and R.Ruf, Physical Review Letters, vol.65, p247(1990))に開示されている。強磁性体探針を用いたこれらの観察例では、磁化の向きがコントラストとして表示されている。

【0005】ところが、これらの公知例で得られる像は表面の凹凸像にスピニ情報が重畠したものであり、表面形態及びスピニ配置が未知な実際の試料表面からスピニ像のみを取り出すことはできないという欠点があった。これを解決する方法として、バイアス電圧に対するスピニ偏極度の違いを利用する方法が特開2000-131215号公報及び文献(M.Bode, M.Getzlaff, and R.Wissendangerer, Physical Review Letters, vol.81, p4256(1998), O.Pietzsch, A.Kubetzka, M.Bode, and R.Wissendangerer, Physical Review Letters, vol.84, p5212(2000))に開示されている。

【0006】しかしながら、この種の装置にあっても次のような問題を避けることは困難であった。即ち、探針は強磁性であるため、試料と探針の互いの磁気的な影響が発生し、測定精度が劣化する可能性がある。また、試料表面の凹凸が激しい場合、探針が試料表面に接触することを避けられず、探針が破損しやすいという欠点があった。

【0007】

【発明が解決しようとする課題】このように、従来のスピニ偏極走査型トンネル顕微鏡においては、強磁性体の探針を用いることにより磁性体試料表面のスピニ情報を得ることはできるものの、探針が強磁性であるため試料と探針の互いの磁気的な影響が発生する可能性があり、また探針が破損しやすいという欠点があった。

【0008】本発明は、上記事情を考慮して成されたもので、その目的とするところは、試料と探針との磁気的相互作用なしにスピニ検出を行うことができ、且つ表面凹凸が激しい試料に対しても探針の破損を防止することのできるスピニ偏極走査型トンネル顕微鏡を提供することにある。

【0009】

【課題を解決するための手段】(構成) 上記課題を解決するために本発明は次のような構成を採用している。

【0010】即ち本発明は、試料表面の磁気スピニ状態を数nm以下の空間分解能で観察するためのスピニ偏極走査型トンネル顕微鏡において、先端部から所定距離以内の領域に磁性電極を被着したカーボンナノチューブからなる探針と、前記磁性電極に対し交流磁場を印加して該磁性電極の磁化方向を周期的に変化させる磁場発生機構と、前記探針を試料表面に対して相対的に走査させる走査機構と、前記探針と試料との間に所定の電圧を印加するバイアス電圧源と、前記探針と試料との間に流れるトンネル電流を検出する電流検出機構と、前記トンネル電流の平均値が一定となるように前記探針を高さ方向に駆動する駆動機構と、前記磁化方向の変化に伴うトンネル

ル電流の交流応答信号成分を抽出して試料表面の磁気スピニ状態を検出する磁気スピニ検出機構とを具備してなることを特徴とする。

【0011】ここで、本発明の望ましい実施態様としては次のものが挙げられる。

(1) 磁性電極材料は、Fe, Co, Ni, Cr, Mn, 若しくはこれらの少なくとも一つを含む合金、又は化合物であること。

(2) 磁性電極は、カーボンナノチューブの先端からスピニ拡散長（一般には数100nm）以内の距離に配置されていること。

(3) 試料と探針との距離を0.1nmから10nmに保つこと。

(4) 磁場発生機構はコイルからなり、交流電流を供給されるものであること。さらに、交流電流の周波数は100Hz～100kHzであること。

(5) 検出されたトンネル電流の交流応答信号成分を画像化する手段を設けたこと。

【0012】また本発明は、磁気情報を再生するための再生装置において、磁気記録に供される磁気記録媒体と、先端部から所定距離以内の領域に磁性電極を被着したカーボンナノチューブからなる探針と、前記磁性電極に対し交流磁場を印加して該磁性電極の磁化方向を周期的に変化させる磁場発生機構と、前記探針を磁気記録媒体表面に対して相対的に走査させる走査機構と、前記探針と磁気記録媒体との間に所定の電圧を印加するバイアス電圧源と、前記探針と磁気記録媒体との間に流れるトンネル電流を検出する電流検出機構と、前記トンネル電流が一定となるように前記探針を高さ方向に駆動する駆動機構と、前記磁化方向の変化に伴うトンネル電流の交流応答信号成分を抽出して磁気記録媒体表面の磁気スピニ状態を検出する磁気スピニ検出機構とを具備してなることを特徴とする。

【0013】(作用) 本発明では、先端部から所定距離以内の領域に磁性電極を被着したカーボンナノチューブから探針を構成している。カーボンナノチューブは、スピニ拡散長が数100nmを越えることが報告されており、その一端側からスピニを持った電子を流すとスピニ状態を保ったまま電子が流れるという特徴がある。従って、カーボンナノチューブの先端からスピニ拡散長以内の距離に磁性電極を設けておくと、磁性電極の磁化方向と電子スピニ方向との関係に応じて磁気抵抗が変わり、トンネル電流も変化する。つまり、上記のようにカーボンナノチューブ及び磁性電極からなる探針を用いても、探針先端を強磁性体で形成した場合と同様に試料表面の磁気スピニ状態を測定することが可能となる。

【0014】そしてこの場合、探針自体は非磁性（探針の先端はカーボンナノチューブであり非磁性体）であるため、試料磁化による探針磁化の影響或いはその逆を避

けることができる。さらに、カーボンナノチューブは高い弾性率を有することから、仮にカーボンナノチューブの先端が試料表面に接触しても問題はなく、探針の破損を防止することが可能となる。

【0015】

【発明の実施の形態】実施形態を説明する前に、本発明の基本原理について説明する。

【0016】カーボンナノチューブは、グラファイトシートを螺旋状に丸めたチューブ状の構造を持つ。チューブは単層のものと多層のものがあるが、本発明の探針としては何れも使用できる。このカーボンナノチューブの一端である先端（A）は、試料表面に0.1nmから10nmの間隔を隔てて配置される。その高さは、カーボンナノチューブと試料間に流れるトンネル電流の平均値が一定の値となるように走査中に逐次高さ調整される。カーボンナノチューブの他端である基端（B）側には磁性電極を設ける。この磁性電極は、カーボンナノチューブの先端（A）からスピニ拡散長（数100nm）以下、例えば800nm以下に設置されれば、完全な端でなくてよい。先端（A）からの距離はさらに好ましくは500nm以下である。

【0017】磁性電極は、カーボンナノチューブを流れてきた試料表面からのトンネル電流を捕えるための電極である。本発明に適応できる電極材料としては、Fe, Co, Ni, Mn, Cr及びこれらを含む合金、パーマロイと呼ばれるNiFe系合金、CoNbZr系、FeTaC系、CoTaZr系、FeAlSi系、FeB系、CoFeB系の軟磁性合金、ホイスラー合金やCr₂O₃, Fe₃O₄, La_{1-x}Sr_xMnO₃などのハーフメタル磁性体が挙げられる。

【0018】パーマロイやアモルファス系の軟磁性材料は、磁性電極を制御する上で好ましく、Co, Fe, CoFe, Fe₃O₄は大きなスピニ信号を得るのに好ましい。また、磁性電極がカーボンナノチューブへの直接接触する部分に3nm以下の厚さを持つCo, CoF_e, 或いはFe₃O₄を形成させ、その上にパーマロイなどの軟磁性体を形成させると、磁性電極の制御性に優れかつ大きなスピニ信号を得ることができる。

【0019】この磁性電極の直近にはその磁化方向を制御する磁場発生機構が取り付けられている。磁場発生機構はコイル状或いは非コイル状の導線から成る。さらにその磁場発生機構へは、電力供給するための10Hz以上の交流電流電源が繋がれている。この交流電流電源からの電流により交流磁場が発生して磁性電極の磁化方向を変調させる。そして、この磁場変調に伴う電極電流の変調応答信号成分検出機構を設けることにより、トンネル電流のスピニ成分を検出することができる。

【0020】磁場発生機構からの発生磁場方向は探針軸に平行になるように探針軸を中心としてコイルを巻く、或いは導線を探針軸に垂直に設けることで、試料の垂直

磁化成分を検出することができる。また、磁場が探針軸に直角になるように電極の横にコイルを設置する、或いは導線を探針軸に平行に設けることで、磁場印加方向と平行な試料の面内磁化成分を検出することができる。磁場発生機構は1つの磁性電極に対して1台或いは複数台並べてもよい。複数台の場合にはここに印加する交流電流の周波数は互いに変えることにより、試料の磁化ベクトルを決定することができる。

【0021】本発明の探針（磁性電極付カーボンナノチューブ）は最終的にはピエゾスキャナー等の駆動系へマウントされるが、磁性電極と駆動系との間には介在物が存在してもよい。図1にその一例を示す。図1（a）では通常の探針11の先に、まずファンデルワールス力でカーボンナノチューブ12を付けた後、接着部へ磁性電極13を蒸着した。そして、通常の探針11をピエゾ素子等の駆動系15へ取り付けた。図1（b）では絶縁体の板14の上に先端が飛び出るようにカーボンナノチューブ12を置いたのち、磁性体を蒸着することで磁性電極13を形成すると共にこれで接着も行った。（a）も（b）も磁性電極13には配線を設けて電流が流れるようにしてある。

【0022】図2は、磁場発生機構としてコイル18を設けた例であり、このコイル18は探針軸を中心として巻かれており、探針の軸方向に磁場が印加する。そして、コイル18に流す電流を交流とすることにより、磁性電極13の磁化方向が変調されるようになっている。

【0023】なお、走査型トンネル顕微鏡としての上記以外の不可欠基本構造は、探針を試料表面に対して相対的に走査させる駆動機構と、探針と試料間にバイアス電圧を印加するバイアス電圧源及び探針と試料間に流れるトンネル電流を検出する電流検出機構である。本発明のスピニ偏極走査型トンネル顕微鏡は、基本構造と同じくしてそのまま再生装置に用いることができる。このような再生装置は、特に高密度記録媒体の再生に適している。

【0024】以下、本発明の詳細を図示の実施形態について説明する。

【0025】（第1の実施形態）図3は、本発明の第1の実施形態に係るスピニ偏極走査型トンネル顕微鏡の基本構成を示す図である。

【0026】探針30は、例えば前記図1（a）に示す構造となっており、カーボンナノチューブ32及び磁性電極33等からなる。この探針30は基端側がピエゾスキャナー35に固定され、先端（カーボンナノチューブ側）が試料20の表面に対して相対走査されるようになっている。探針30の近傍には、磁性電極33に磁場を印加するための磁場発生機構41が配設されている。この磁場発生機構41は、例えば前記図2に示すように探針軸を中心に巻かれたコイルであり、交流電源44により駆動されるようになっている。

【0027】探針30の磁性電極33には、STM制御／信号処理部40によりバイアス電圧が印加される。このバイアス電圧の印加により探針30と試料20との間に流れるトンネル電流は、トンネル電流増幅器43により増幅されて、STM制御／信号処理部40及び後述する位相検波増幅器45に入力される。そして、STM制御／信号処理部40では、トンネル電流の平均値が一定となるように、ピエゾスキャナー35を駆動するためのピエゾ制御信号を出力するようになっている。

10 【0028】また、交流電源44による交流信号は位相検波増幅器45に変調信号として供給される。位相検波増幅器45では、交流電源44からの変調信号を基に、増幅器43を介して得られるトンネル電流が同期検波される。ここで、トンネル電流の中には磁気スピンに依存した成分があり、これは磁場発生機構41を交流駆動することにより大きく変化するため、交流駆動に応じて信号を取り出せばスピン成分を取り出すことができる。即ち、上記のように交流信号に同期してトンネル電流を検波することにより、試料表面の磁化成分のみを検出することが可能となる。

【0029】なお、上記の説明では、探針30の試料表面上での走査及び探針30の上下動にピエゾスキャナー35を用いたが、ピエゾスキャナー35は探針30の上下動のみに用い、探針30を試料表面上で走査するため試料20を載置したステージを移動させるようにしてよい。

【0030】上記構成において、カーボンナノチューブ32へ磁性電極33としてCoFe／パーマロイの積層電極を設けてピエゾスキャナー35にマウントし、スピニ偏極走査型トンネル顕微鏡のテストを行った。積層電極としては、Co／パーマロイ、Fe／パーマロイ等も好ましく、このパーマロイの代わりに軟磁性アモルファスも好ましい。CoFe、Co、Feがカーボンナノチューブに接する。CoFe、Co、Feの厚さは0.3～2nm、パーマロイ等の軟磁性体の厚さは1～30nmが好ましい。磁性電極33を磁化させるための磁場発生機構41としては、図2に示すように、磁性電極を中心軸としてコイルを巻き、交流電源44により777Hzの周波数で10Gの磁場発生を行い、トンネル電流のうち磁場変調と同期した成分を位相検波増幅器45により検出した。

【0031】試料20としてCo垂直磁化膜を用い、トンネル電流が0.2nAになるように探針30の高さを制御しながら探針30を試料20上で走査した。探針30の高さ位置を画像信号とした画面からは試料表面のトポロジーが、位相検波増幅器45の出力を画像信号としたものはトポグラフ像とは無関係なコントラストを示し、このコントラストは試料20への3kGのパルス磁場印加で消失した。また、非磁性基板部分からの信号は

50 ゼロであった。以上の結果から、位相検波増幅器45の

出力信号が試料表面の磁化状態を検出していることを確認した。

【0032】また、図3と同様のスピン偏極走査型トンネル顕微鏡の構成で、カーボンナノチューブ32の先端(A)から距離300nmのところに磁性電極33としてのCoFe電極を設けた探針30を用い、Co試料20に対してスピン信号強度を位相検波増幅器45により求めた。比較例として、非磁性であるタングステン探針のこれも先端から距離300nmのところにCoFe電極を設けたものを用い、Co試料に対してスピン信号強度を位相検波増幅器45により求めた。

【0033】変調応答信号の大きさをトンネル電流値で規格化した抵抗変化率は、前者が5%であったのに対し、後者はノイズレベル以下で検出不能であった。本実施形態で抵抗変化率が変わるのは、カーボンナノチューブ32はスピン拡散長が長く、試料表面のスピン状態をそのまま保持して磁性電極33に達し、ここで磁気抵抗効果が起こるためである。また、電極位置をカーボンナノチューブ32の先端(A)から距離150nmのところに設けて比較実験を行ったところ、抵抗変化率は15%以上に増大した。この結果から、磁性電極33の設置位置はカーボンナノチューブ32の先端(A)に近い方が望ましいのが分かる。

【0034】また、図3と同様のスピン偏極走査型トンネル顕微鏡を用い、カーボンナノチューブ32からなる探針30と通常のタングステン探針とを、10nmの表面凹凸を有する試料表面を走査させて探針の耐性テストを行った。その結果、タングステン探針では3回のスキャンで像がダブルとなったのに対し、カーボンナノチューブによる像は変化しなかった。この結果は、カーボンナノチューブの耐衝撃性が高いを示している。

【0035】このように本実施形態によれば、先端部からスピン拡散長以内の距離に磁性電極33を被着したカーボンナノチューブ32から探針30を構成し、磁場印加機構41により磁性電極33の磁化方向を変調しながらトンネル電流を検出することによって、探針先端を強磁性体で形成した場合と同様に試料表面の磁気スピン状態を測定することができる。

【0036】また本実施形態では、探針30の先端はカーボンナノチューブ32であり非磁性体であるため、試料磁化による探針磁化の影響或いはその逆を避けることができる。さらに、カーボンナノチューブ32は高い弾性率を有することから、仮にカーボンナノチューブ32の先端が試料表面に接触しても問題ではなく、探針30の破損を防止することが可能となる。つまり、試料と探針との磁気的相互作用なしにスピン検出を行うことができ、且つ表面凹凸が激しい試料に対しても探針の破損を防止することができる。

【0037】(第2の実施形態)図4は、本発明の第2の実施形態に係わる再生装置の要部構成を示す断面図で

ある。

【0038】図中の60は探針であり、この探針60は先の実施形態と同様に、カーボンナノチューブ62及び磁性電極63等から構成されている。65はトンネル電流を一定にするために探針60を微小駆動する微小駆動部、67は複数の探針60を同時に駆動するための大領域駆動部、69は磁場発生機構、70は磁気記録媒体を示している。

【0039】本実施形態では、磁性電極63を有するカーボンナノチューブ62を微小駆動部65にマウントして1ユニットとしたものを、複数ユニット1列に並べてさらに大きな距離へ対応した大領域駆動部67へマウントした。これにより磁気ヘッド部を構成した。磁気ヘッド部の複数ユニットに対するバイアス電圧源(図示せず)及び磁場発生機構69はそれぞれ1つにした。そして、複数のカーボンナノチューブ62を磁気記録媒体70の表面に微小間隙を隔てて配置し、これらを相対的にスキャンするものとした。

【0040】より具体的には、磁性電極63、磁場発生機構69、微小駆動部65としてのピエゾ素子等は微細加工により作製した。探針60は50本並べて探針アレイとした。磁場発生機構69は、磁性電極63の側部に隣接配置された細線からなり、ここに流す電流により磁性電極63に対しカーボンナノチューブ62の軸方向を向いた磁場がかかる。配線を設けた磁性電極63を含むカーボンナノチューブアレイと磁場発生機構69とを1ユニットとして、磁気記録媒体70の上へセットした。

【0041】磁気記録媒体70には、直径7nmの柱状からなるパターンを各記録ビットとした媒体を用いた。

30 この磁気記録媒体70に対し磁気ヘッド部全体を相対的に移動させる。図4では、磁気ヘッド部を紙面左右方向及び紙面表裏方向に移動させている。紙面左右方向の移動距離dは、カーボンナノチューブ間の距離をrとするとき、最大でd=rとなることが好ましい。カーボンナノチューブの本数をnとすると、全体では $(n+1) \times d$ の幅を持つ媒体領域の読み込みが可能となる。

【0042】磁気ヘッド部を移動させながら、各探針により移動距離範囲内の記録ビット情報を読み取る。具体的には、各磁性電極からの信号のうち磁場変調応答信号成分を位相検波増幅器により検出して各出力信号とする。なお、図では1列のアレイからなるが、50×50のようなマトリックスアレイにすることで更に高速処理も可能である。なお、図4の配置において紙面に垂直方向の駆動については、1列アレイの場合には媒体長さに対応した距離を移動させる必要があるが、マトリックスアレイの場合には、隣の探針までの移動距離で済む。

【0043】以上の方法での再生信号を検討した結果、1Tbpsの記録密度に対応した磁気記録媒体の記録状態を読み込めるることを確認した。

50 【0044】このように本実施形態によれば、カーボン

ナノチューブ及び磁性電極等からなる探針を磁気ヘッドとして用いることにより、磁気記録媒体に記録された磁気情報を読み出すことができる。しかも、探針による磁気スピンの分解能が極めて高いため、1 Tbpsの記録密度に対応した磁気記録媒体の読み出しも可能となる。また、探針を列状又はマトリックス状に配列することにより、読み出しの高速処理をはかることができる。また、第1の実施形態と同様に、探針の先端部にカーボンナノチューブを用いていることから、探針と磁気記録媒体との磁気的相互作用を無くすことができ、且つ探針の長寿命化をはかることができる。

【0045】なお、本発明は上述した各実施形態に限定されるものではない。磁性電極を磁化させる方向は必ずしも探針軸方向に限るものではなく、探針軸と水平の方向であってもよい。水平方向に磁化させる場合は、磁性電極の側部にコイルを配置したり、磁性電極の上部に細線を設ければよい。さらに、磁場発生機構は必ずしも1つに限るものではなく、複数個設け各々の合成磁場を利用してもよい。磁性電極を設ける位置はカーボンナノチューブの先端からスピンドル長以内の距離であればよく、通常は800 nm以内であればよい。さらに、磁性電極の材料は仕様に応じて適宜変更可能である。

【0046】また、第2の実施形態においては、探針を複数にしたが、1つの探針で磁気記録媒体の情報を読み込むようにしてよいのは勿論のことである。さらに、第2の実施形態において、磁気記録媒体を円板状に形成し、カーボンナノチューブを磁気記録媒体の中心を通る直線上に配置し、磁気記録媒体を回転させて磁気情報を読み出すようにすることも可能である。

【0047】その他、本発明の要旨を逸脱しない範囲で、種々変形して実施することができる。

【0048】

【発明の効果】以上詳述したように本発明によれば、スピンドル走査型トンネル顕微鏡の探針を非磁性のカーボンナノチューブと、このカーボンナノチューブの先端か

ら所定距離以内の領域に配置した磁性電極で構成することにより、磁性材料の磁気構造或いは強磁性体の磁区構造を数nm以下の空間分解能で観察することができる。しかも、カーボンナノチューブが非磁性であることから探針磁化と試料磁化の互いの影響を避けることができ、カーボンナノチューブが高い弾性率を有することから表面凹凸が激しい試料に対しても探針の破損を防止することができる。

【図面の簡単な説明】

10 【図1】本発明の基本構成を説明するためのもので、カーボンナノチューブのマウント例を示す図。

【図2】本発明の基本構成を説明するためのもので、磁場発生機構の設置例を示す図。

【図3】第1の実施形態に係わるスピンドル走査型トンネル顕微鏡の全体構成を示す図。

【図4】第4の実施形態に係わる再生装置の基本構成を示す図。

【符号の説明】

11…従来の探針

20 12, 32, 62…カーボンナノチューブ

13, 33, 63…磁性電極

14…絶縁板

15, 35…ピエゾ素子(駆動機構)

18, 41…コイル(磁場発生機構)

20…試料

30, 60…探針

40…STM制御部/信号処理部

43…トンネル電流増幅器

44…交流電源

30 45…位相検波増幅器

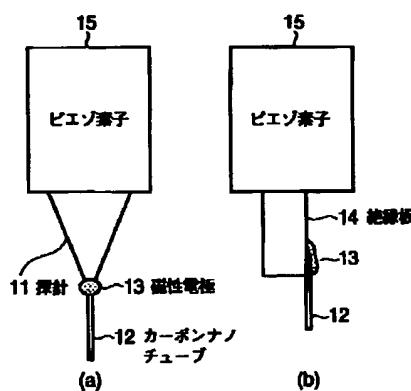
65…微小駆動部

67…大領域駆動部

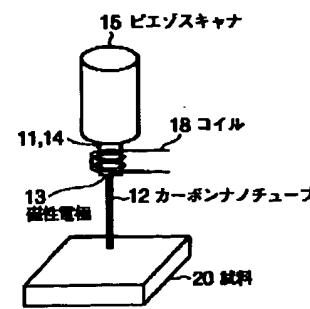
69…細線(磁場発生機構)

70…磁気記録媒体

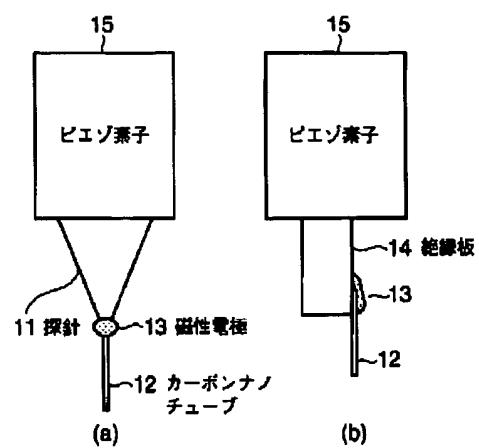
【図1】



【図2】

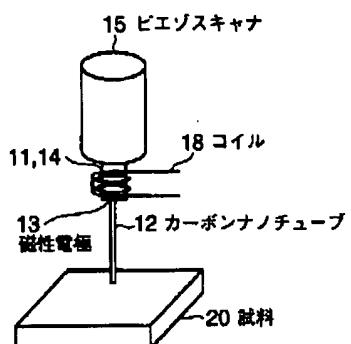


Drawing selection drawing 1

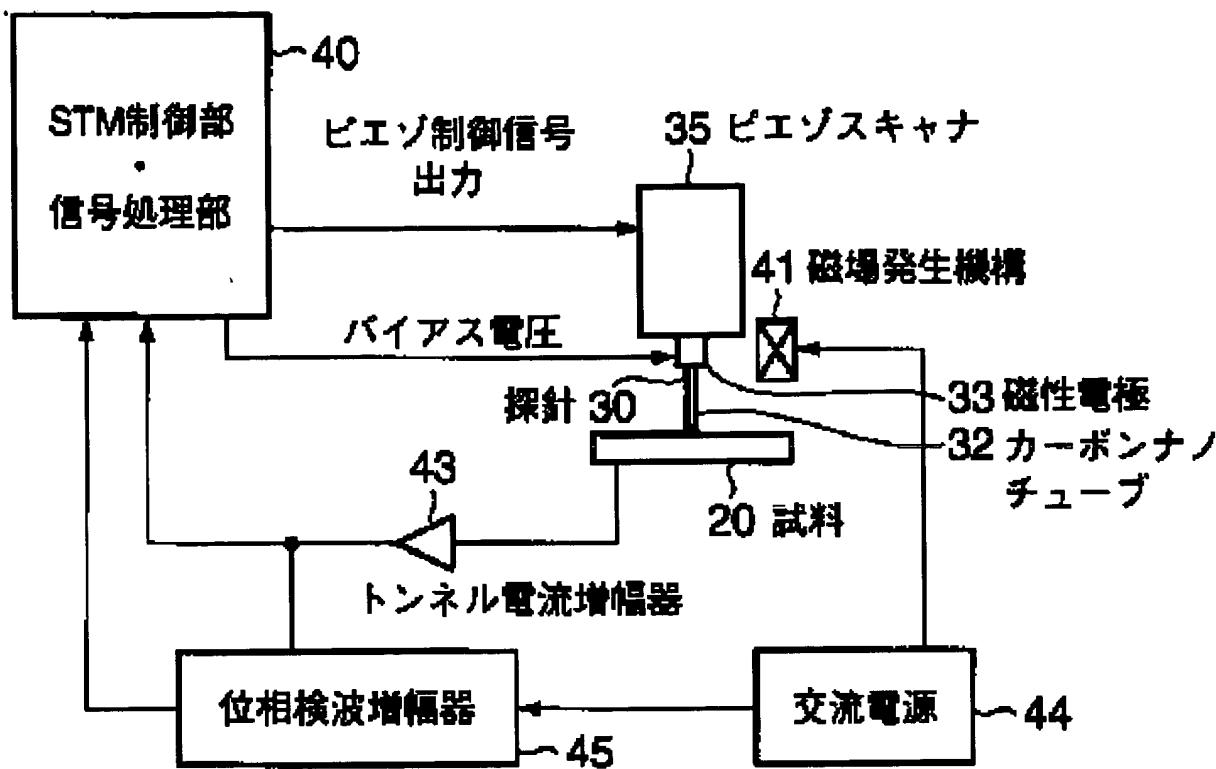


[Translation done.]

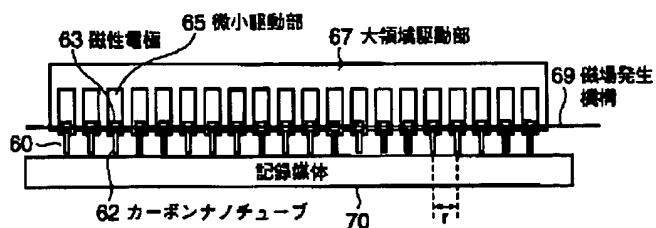
Drawing selection drawing 2



[Translation done.]

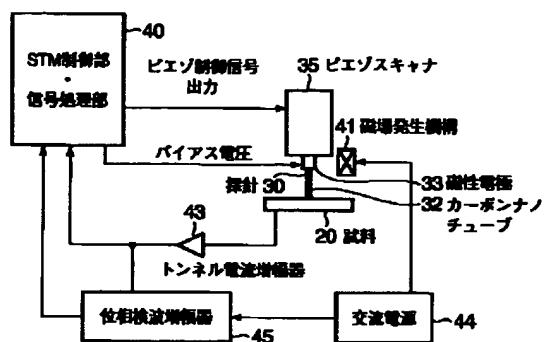


Drawing selection drawing 4



[Translation done.]

【図3】



【図4】

